At-sea validation of *AIRS* radiances

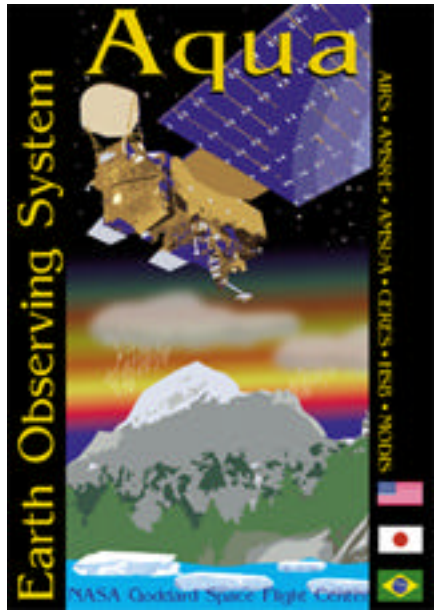
Peter Minnett

Meteorology and Physical Oceanography

Rosenstiel School of Marine and Atmospheric Science

University of Miami

AIRS Validation Meeting
Pasadena, 8 November, 2001



The need for validation

The retrieved fields are validated to confirm the procedures used to generate them from the radiometer data are performing as believed.

If the validation is done well, the error characteristics, referred to a temperature standard, are also determined. Ideally, the measured top-of-atmosphere radiances are well calibrated and free of significant instrumental artifacts, and the uncertainties in the satellite-derived fields are caused by imperfections in the retrieval algorithm.

At-sea validation with M-AERI

Use Marine-Atmospheric Emitted Radiance Interferometer (M-AERI) to validate:

- SSTs from AVHRR
- SSTs from MODIS
- SSTs from TRMM
- SSTs from AIRS
- Atmospheric spectra from AIRS

At-sea validation with M-AERI

Use Marine-Atmospheric Emitted Radiance Interferometer (M-AERI) to validate:

- SSTs from AVHRR
- SSTs from MODIS
- SSTs from TRMM
- SSTs from AIRS
- Atmospheric spectra from AIRS

Ancillary data for AIRS will include:

- Surface wind – anemometers
- Cloud amount – all-sky cameras
- Precipitable water – radiosondes, _wave radiometer
- Rain rate – optical rain gauge
- Surface humidity – chilled mirror
- Atmospheric profiles of temperature and humidity – radiosondes and M-AERI
- Aerosols – Multi-Frequency Rotating Shadowband Radiometers
- Infrared surface emissivity – M-AERI
- Subsurface temperature profiles – SkinDeEP
- Air-sea fluxes

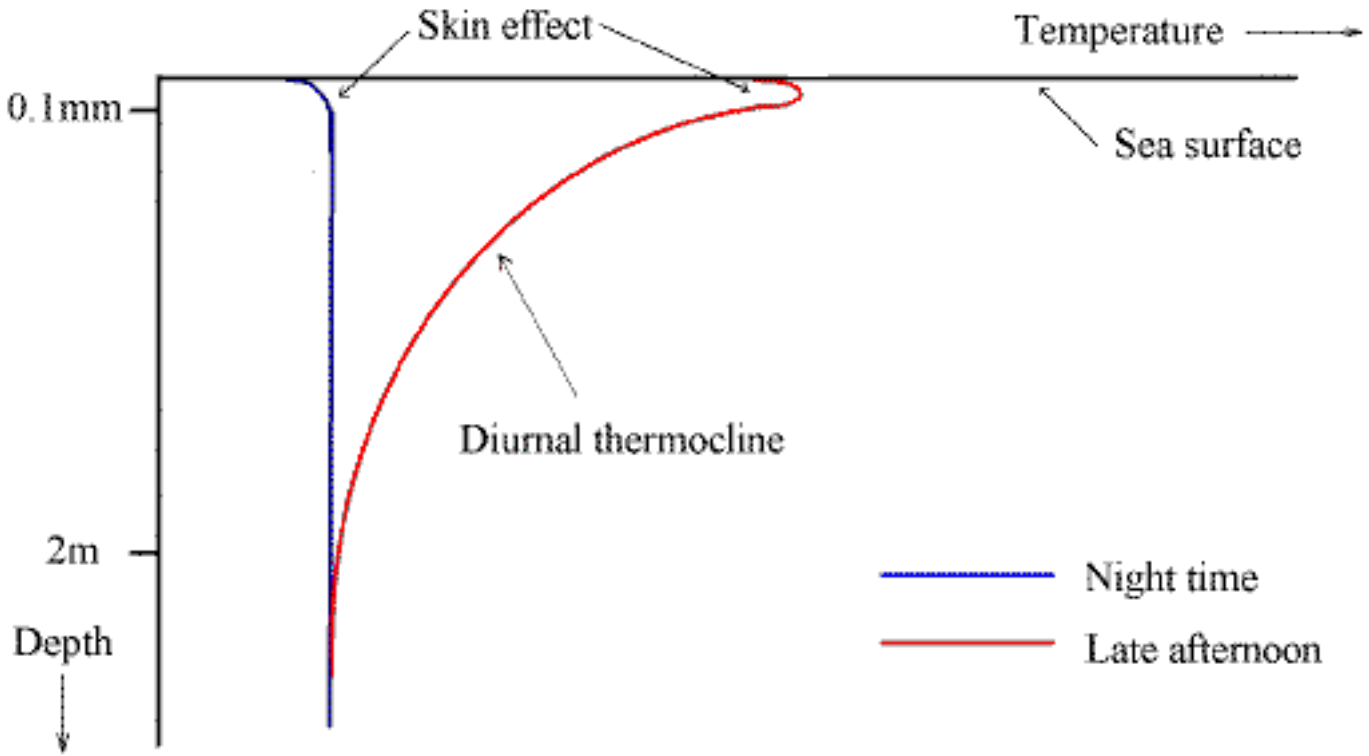
What is SST? – the skin *vs.* bulk debate

The optical depth of sea water at infrared wavelengths is < 1mm. The source of the AIRS signal in the very clear windows is the skin layer of the ocean, which is generally cooler than the subsurface layer because of heat flow from the ocean to the atmosphere.

The conventional meaning of SST is the temperature measured at a depth of a meter or more by a contact thermometer; the so-called bulk temperature.

At the levels of accuracy at which SST needs to be measured for AIRS, skin and bulk temperatures are not the same.

Near surface temperature gradients – ideal, conceptual situation



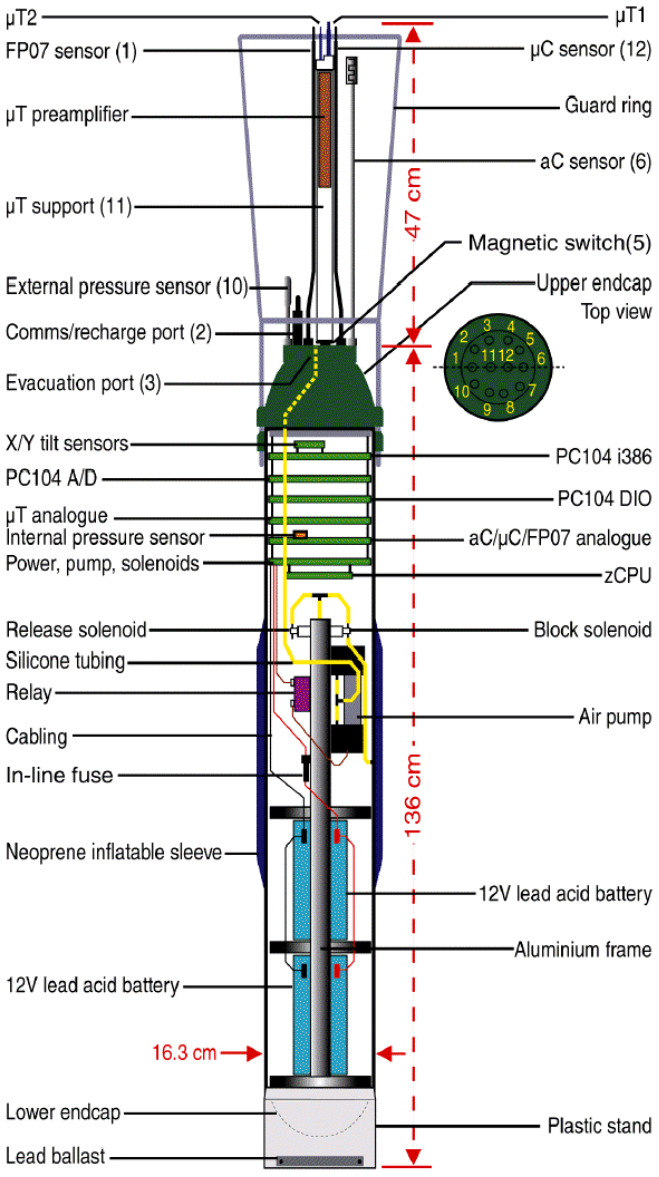
Combined effect of skin and diurnal thermocline effects

- Skin effect responds quickly to changing surface fluxes on time scales of seconds; vertical scale <1mm.

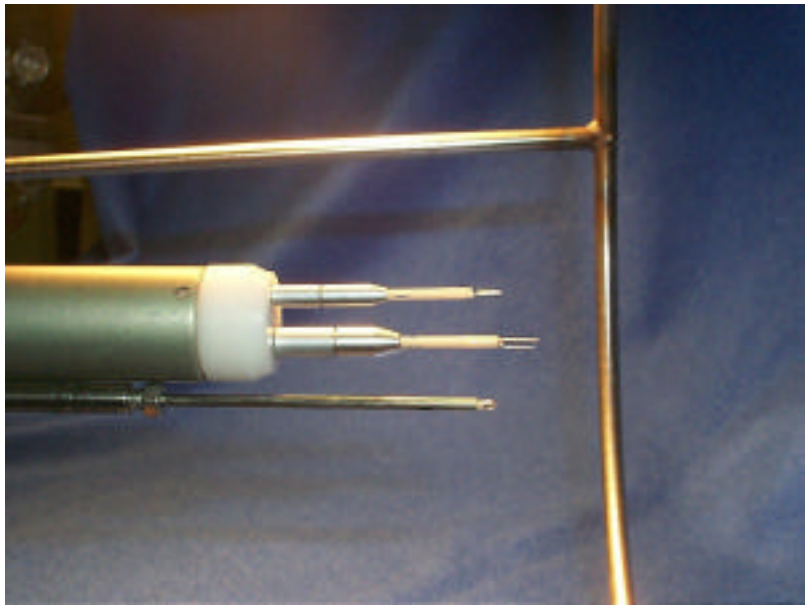
- Diurnal thermocline integrates fluxes, and responds to changing surface fluxes on time scales of minutes to hours; vertical scale of several m.

- Signs of effects are usually opposite.

SkinDeEP

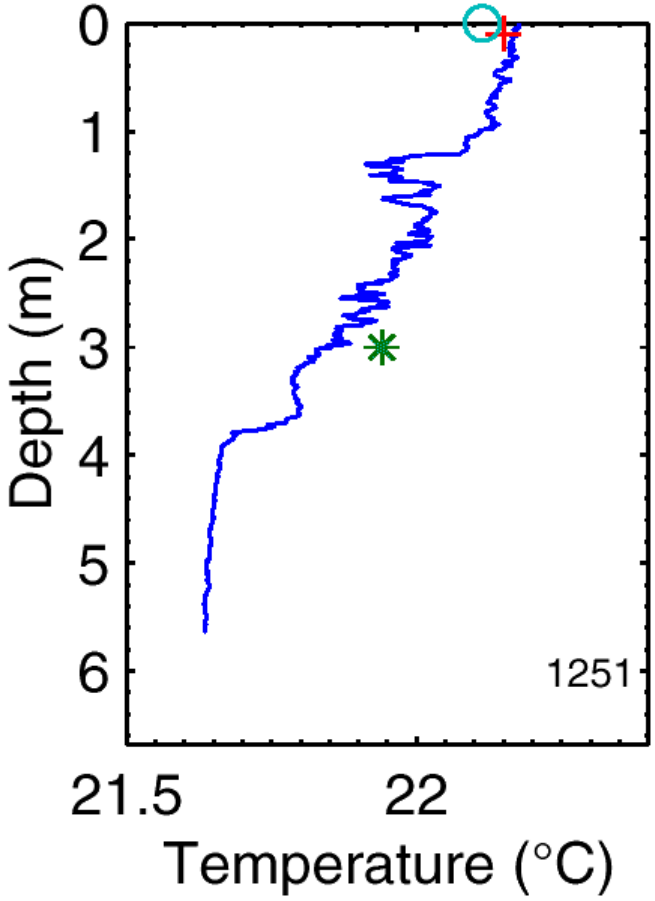


Skin Depth Experimental Profiler



Microstructure probes

Near surface temperature gradients – reality



Profile measured at 12:51 local time on 4 October 1999. Off Baja California, R/V *Melville* MOCE-5 cruise.

Blue line = SkinDeEP* profile

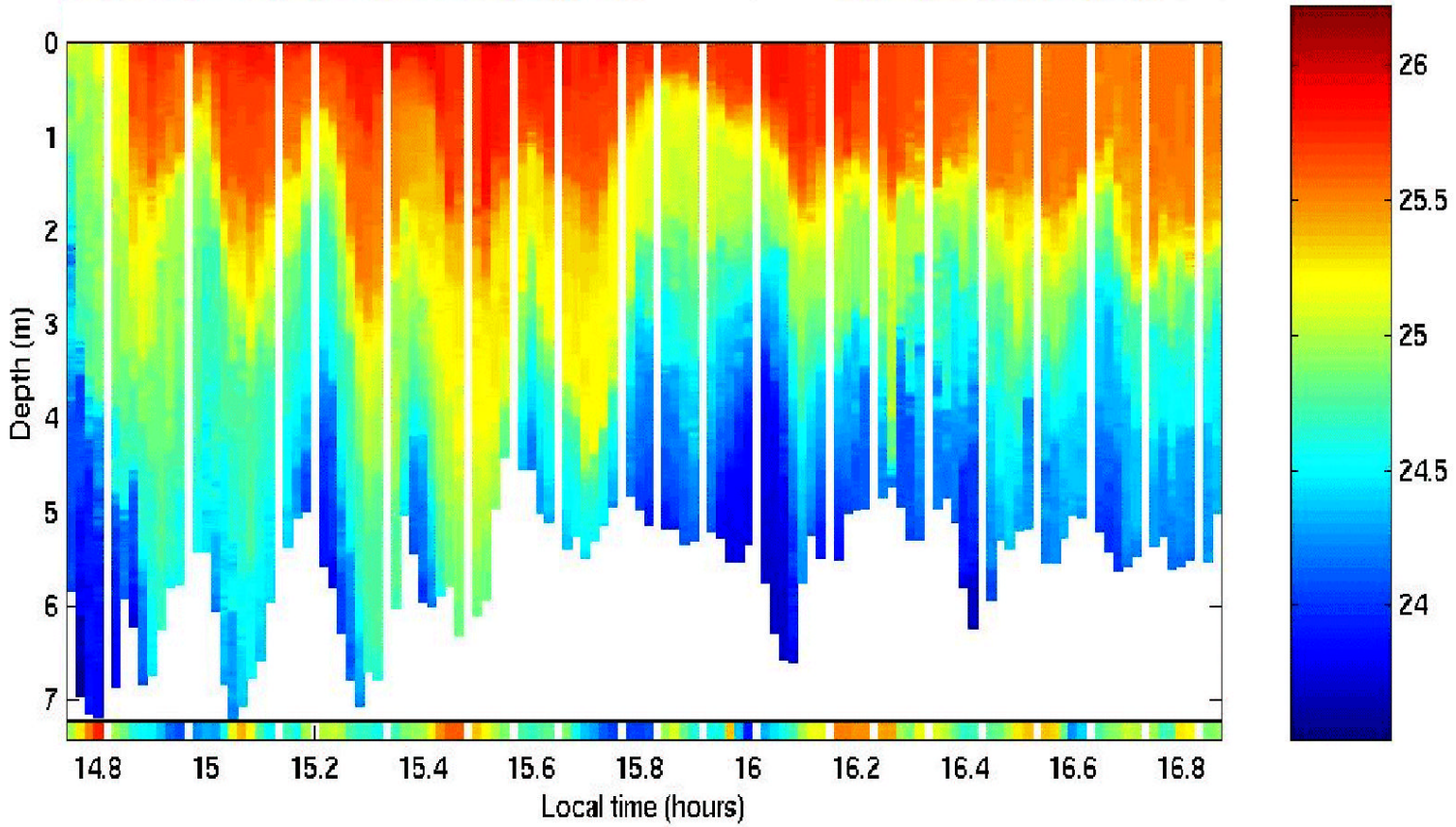
Blue circle = M-AERI skin temp.

Red cross = Float bulk SST at ~0.05m

Green star = Ship thermosalinograph at ~3m

From Ward, B. and P. J. Minnett, 2001. An autonomous profiler for near surface temperature measurements. *Gas Transfer at Water Surfaces.* M. A. Donelan, W.M. Drennan, E.S. Saltzmann and R. Wanninkhof (Eds.) *American Geophysical Union Monograph 127.* 167 - 172.

Time evolution of near surface thermal gradients



SkinDeEP profiles on 12 October 1999. Off Baja California, R/V *Melville*.

From Ward, B. and P. J. Minnett, 2001. An autonomous profiler for near surface temperature measurements. *Gas Transfer at Water Surfaces.* M. A. Donelan, W.M. Drennan, E.S. Saltzmann and R. Wanninkhof (Eds.) *American Geophysical Union Monograph 127.* 167 - 172.

Measurements of skin temperature

Because of the effects of diurnal thermoclines and the skin layer, primary validation of AIRS window radiances should be by reference to surface-level measurements of skin temperature. This can be measured by filter radiometers or spectroradiometers on ships, aircraft or fixed platforms.

The instruments must be well calibrated to reach the level of <0.1K absolute uncertainties. There are few such instruments available. One of which is the M-AERI……

Marine-Atmosphere Emitted Radiance Interferometer

Specifications

Spectral interval	~3 to ~18μm
Spectral resolution	0.5 cm^{-1}
Interferogram rate	1Hz
Aperture	2.5 cm
Detectors	InSb, HgCdTe
Detector temperature	78°K
Calibration	Two black-body cavities
SST retrieval uncertainty	<< 0.1K (absolute)

Laboratory tests of M-AERI accuracy

Target Temp.	LW (980-985 cm^{-1})	SW (2510-2515 cm^{-1})
20°C	+0.013 K	+0.010 K
30°C	-0.024 K	-0.030 K
60°C	-0.122 K	-0.086 K

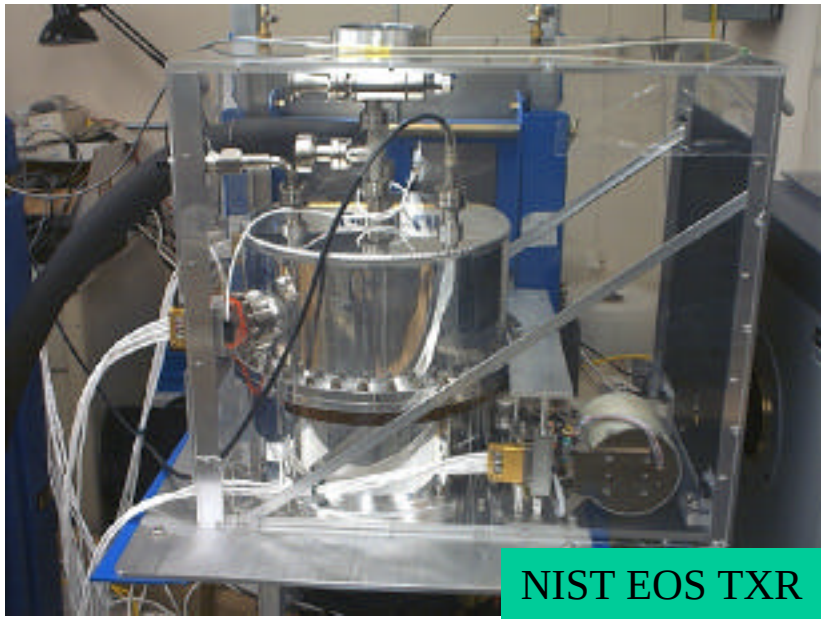
The mean discrepancies in the M-AERI 02 measurements of the NIST water bath blackbody calibration target in two spectral intervals where the atmosphere absorption and emission are low. Discrepancies are M-AERI minus NIST temperatures.

Temperatures are traced to NIST

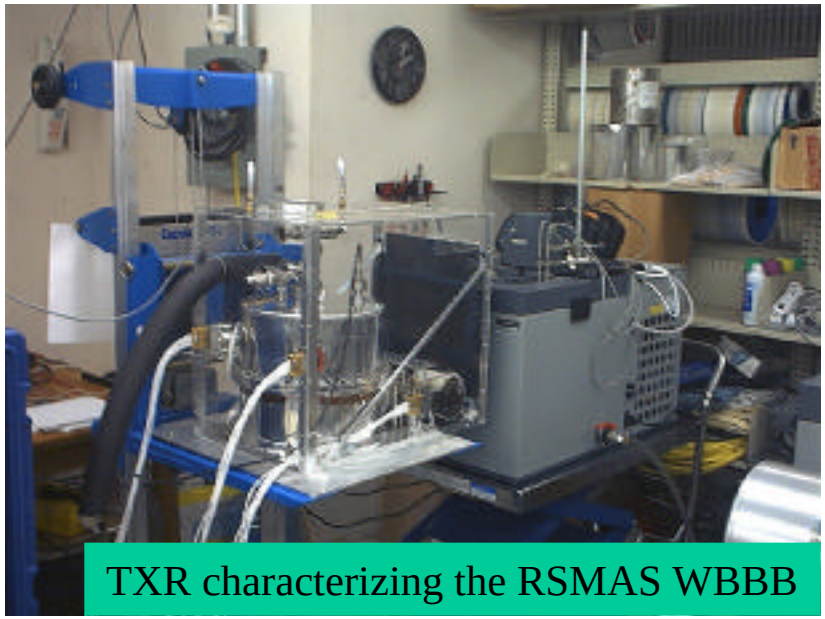
1. on-board black-body cavities have thermometers calibrated to NIST-traceable themometers (SSEC)

2. periodic calibration of M-AERI system with a NIST-designed Water-Bath Black-Body target at RSMAS, using NIST-traceable reference thermometers.

3. RSMAS Water-Bath Black-Body target characterized with NIST EOS TXR

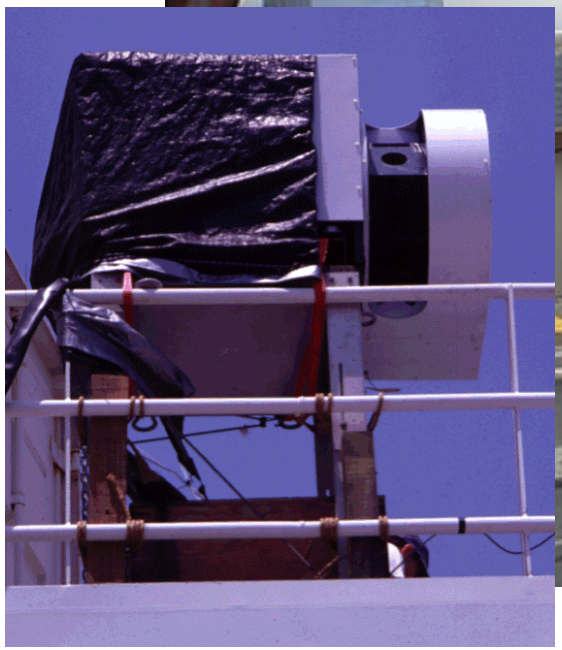


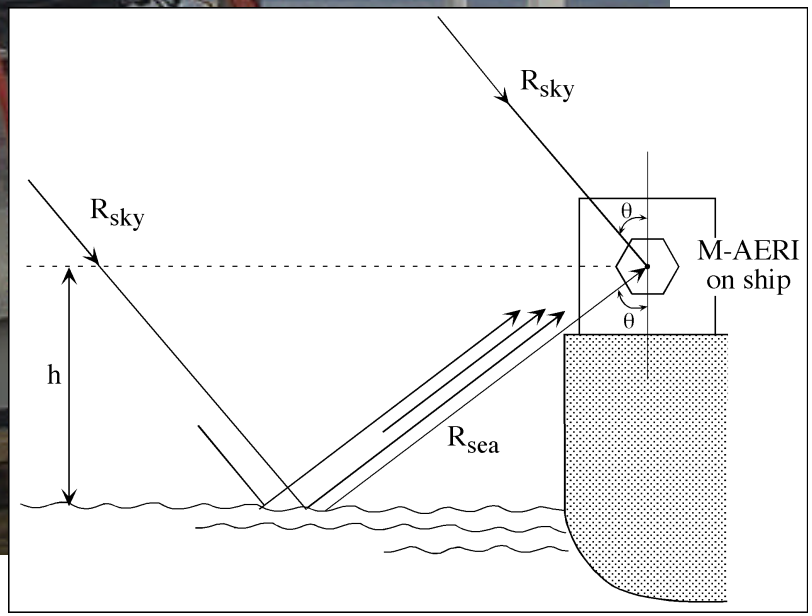
NIST EOS TXR



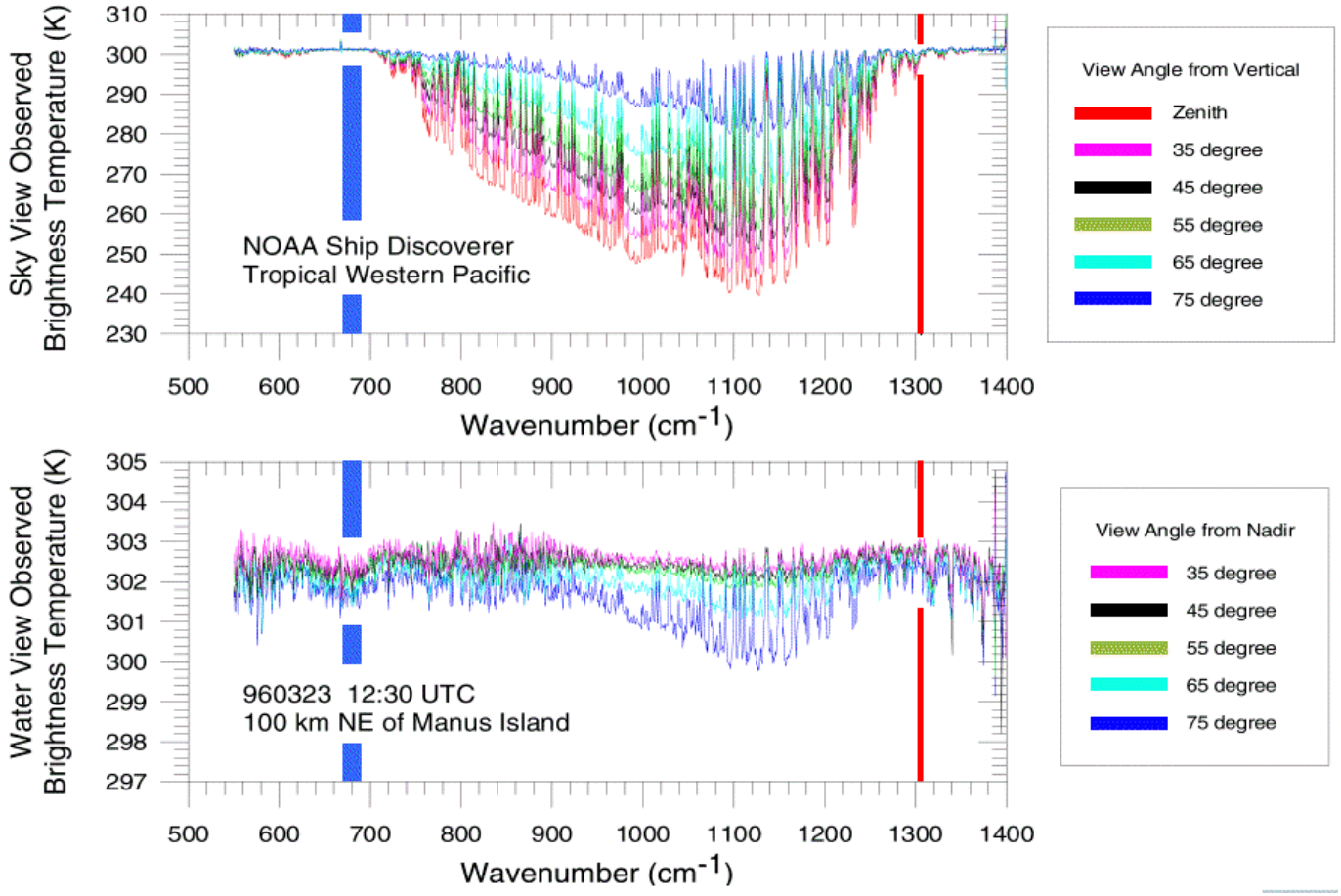
TXR characterizing the RSMAS WBBB

M-AERI on USCGC *Polar Star*, March 2000





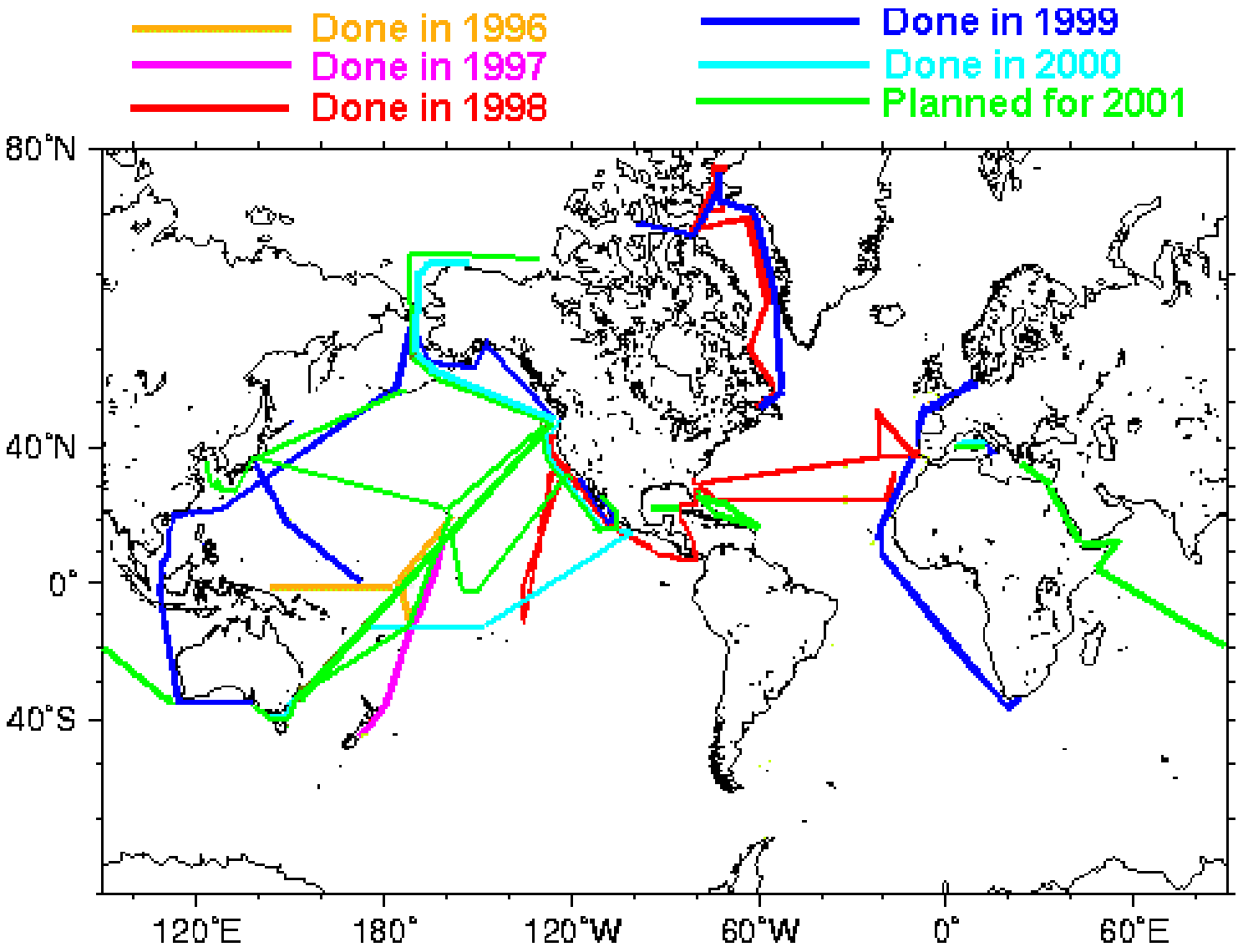
M-AERI spectra



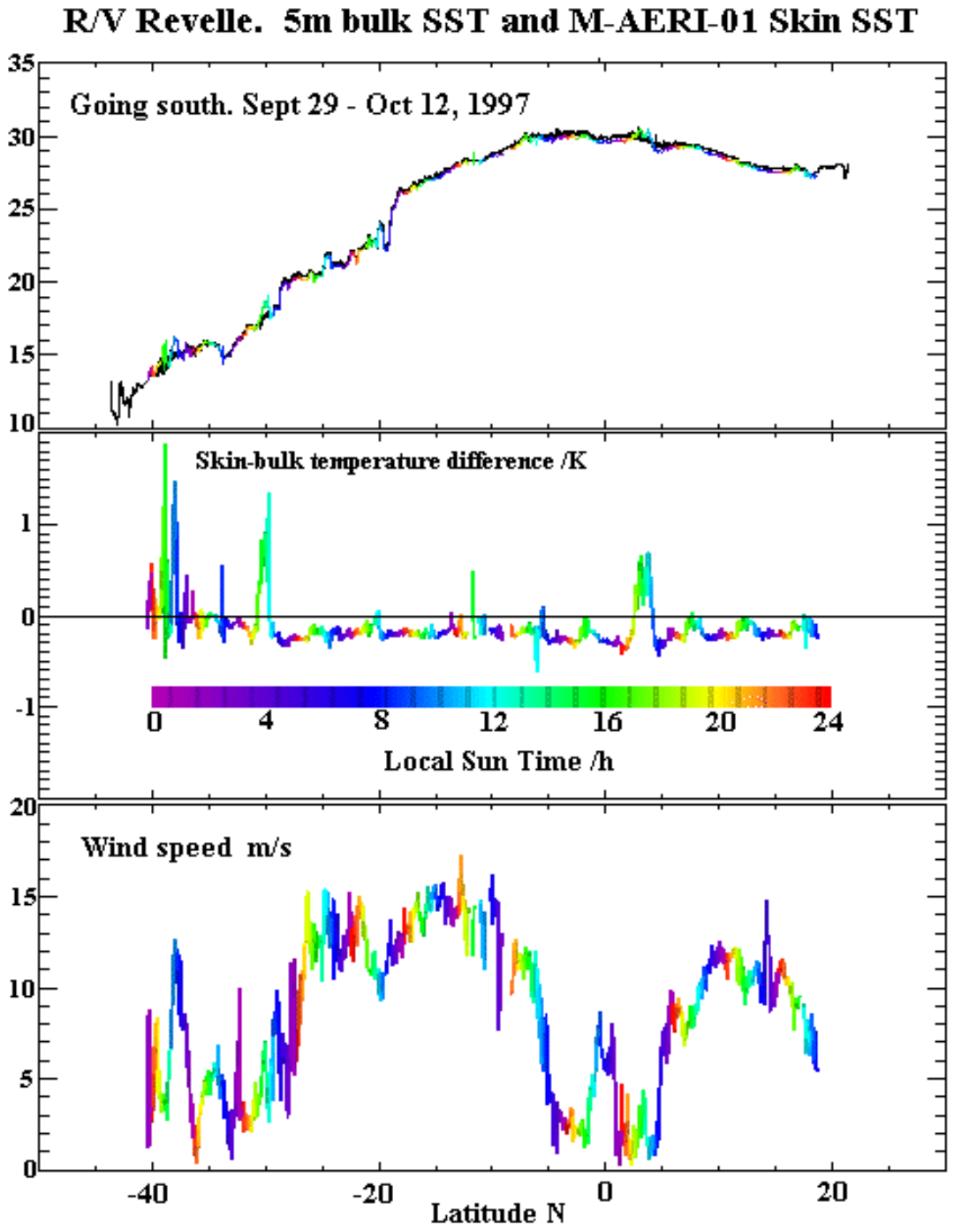
Examples of parts of spectra measured by the M-AERI, represented as temperature, and those intervals where the sky temperatures are smallest indicate where the atmosphere is most transparent. The spikes in the atmospheric spectra are caused by emission lines. The blue bar shows which spectral region is used to measure air temperature, and the red bar skin sea-surface temperature. Note the change in temperature scales of the two panels. These data were taken in the Tropical Western Pacific during the Combined Sensor Program Cruise in 1996.

From: Minnett, P. J., R. O. Knuteson, F.A. Best, B.J. Osborne, J. A. Hanafin and O. B. Brown, 2001. The Marine-Atmosphere Emitted Radiance Interferometer (M-AERI), a high-accuracy, sea-going infrared spectroradiometer. *Journal of Atmospheric and Oceanic Technology*,**18**, 994-1013.

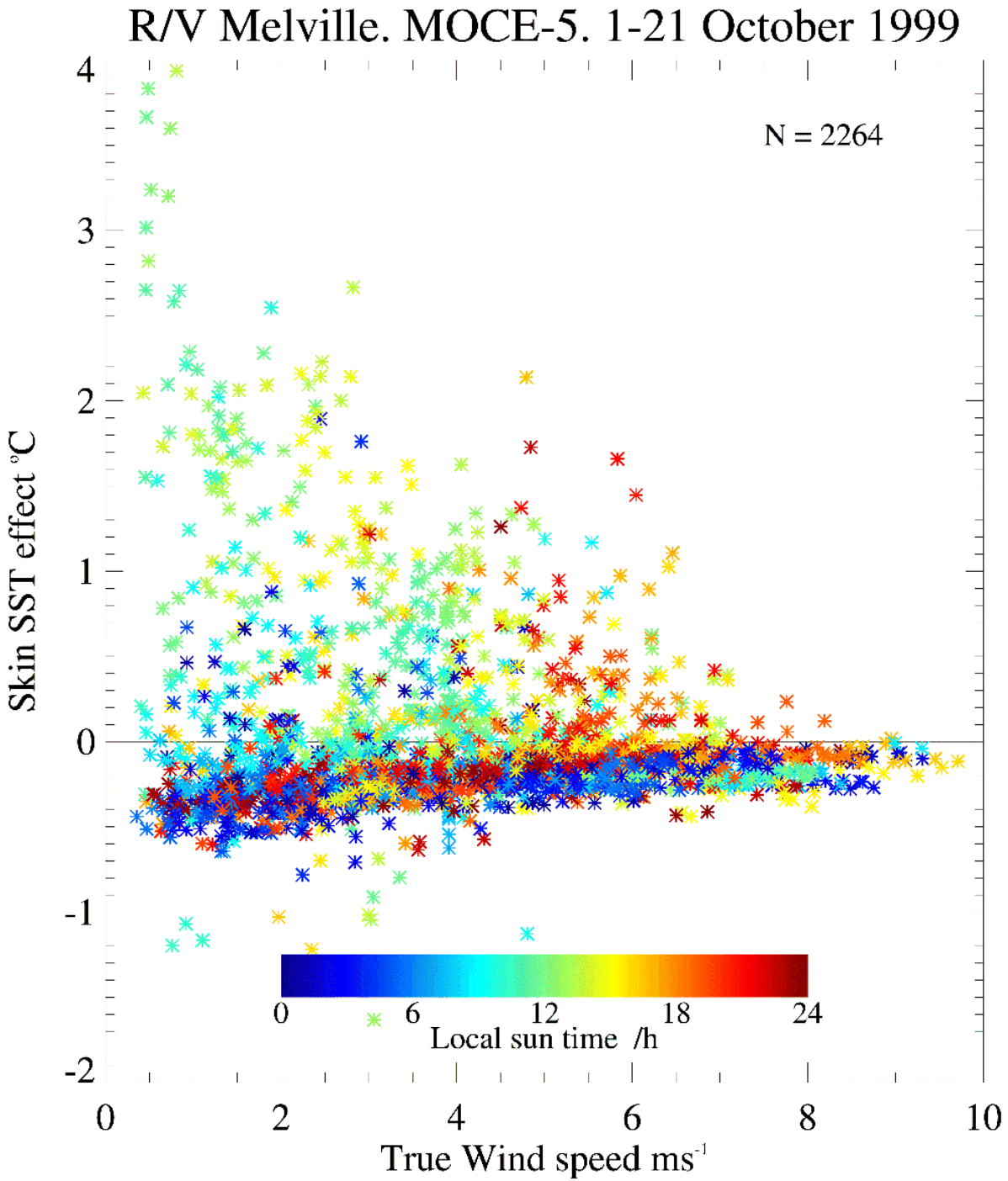
M-AERI Cruises



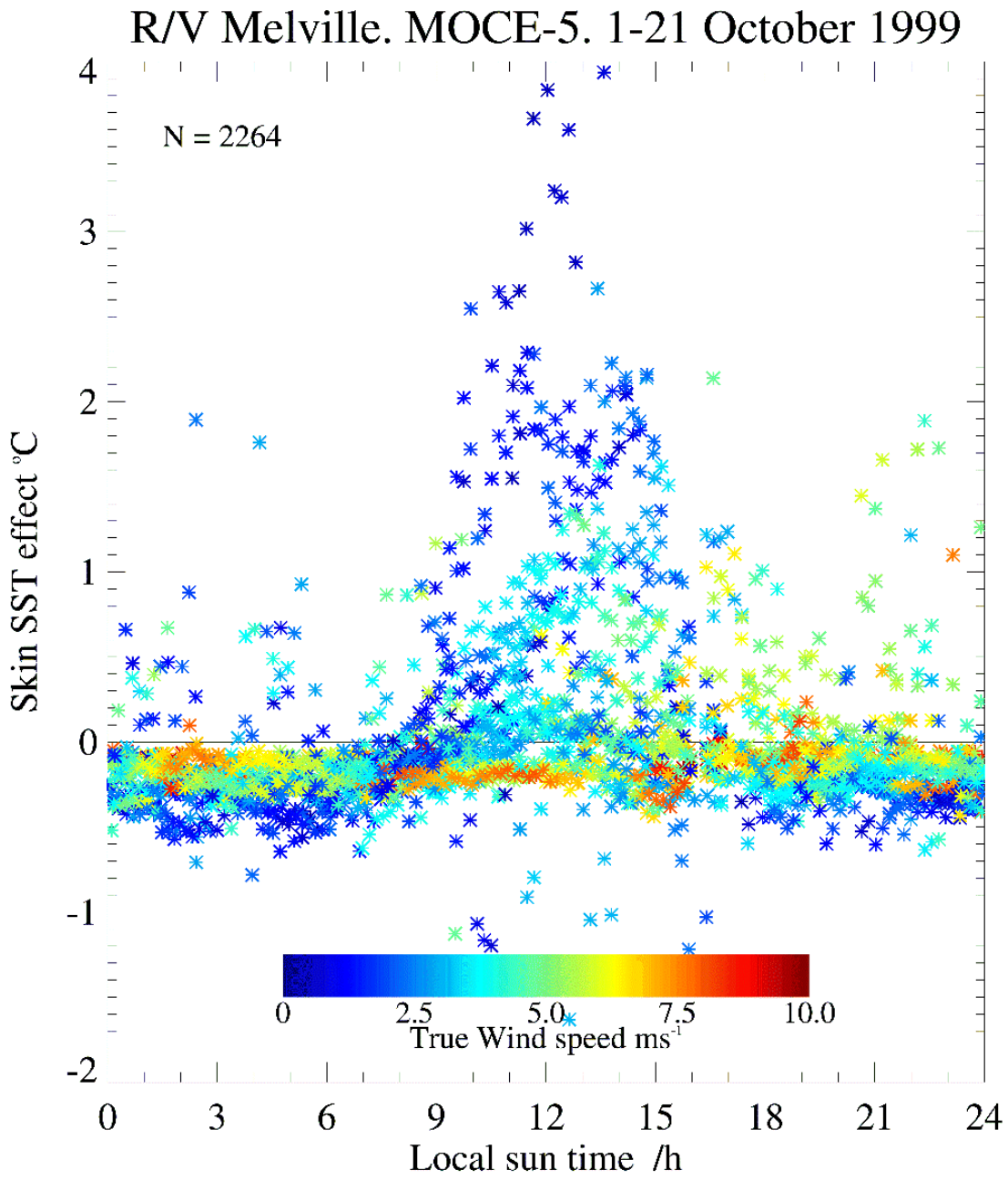
Skin and Diurnal effects – Hawaii to New Zealand



Wind speed dependence of the skin effect

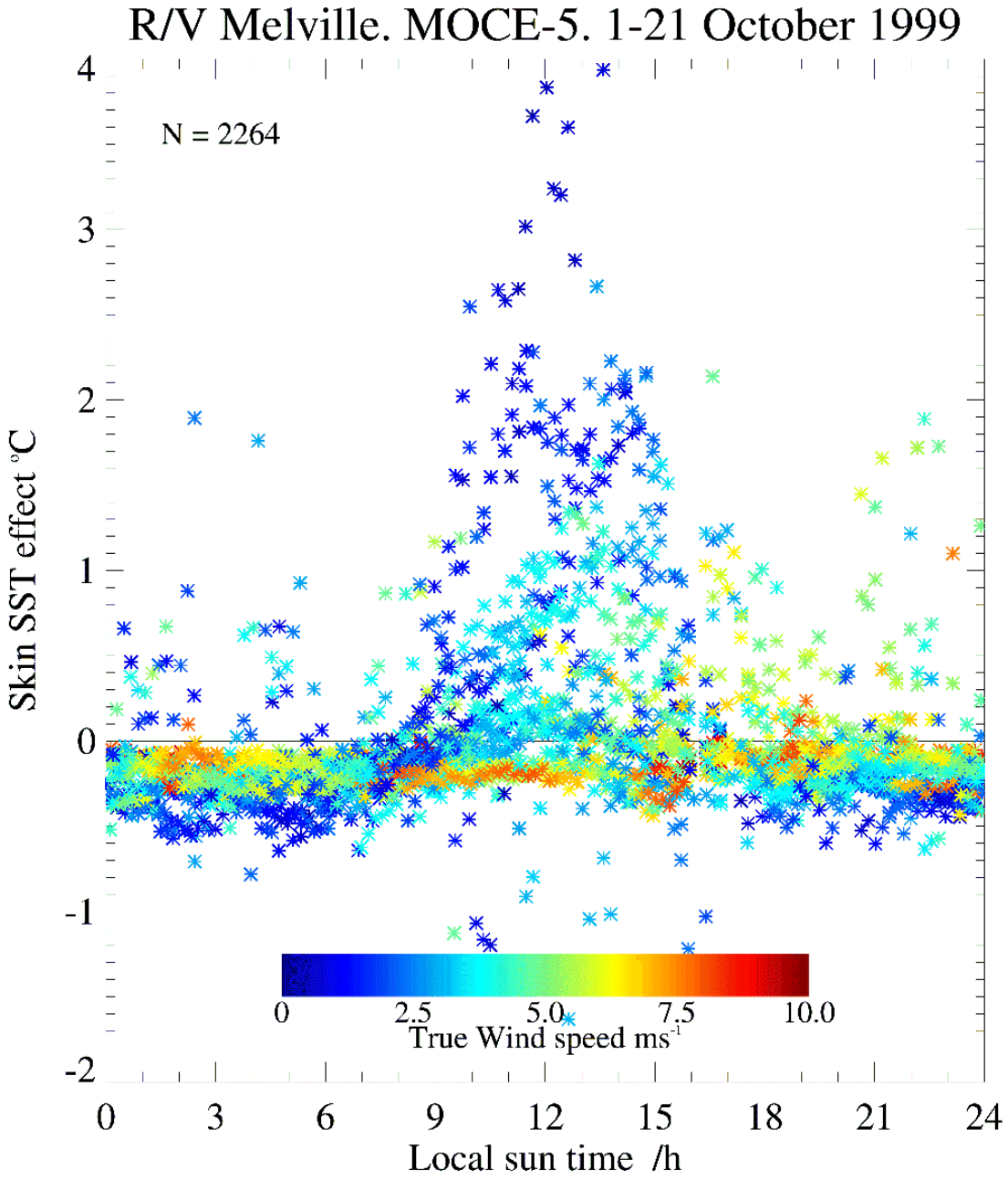


Wind speed dependence of diurnal & skin effects

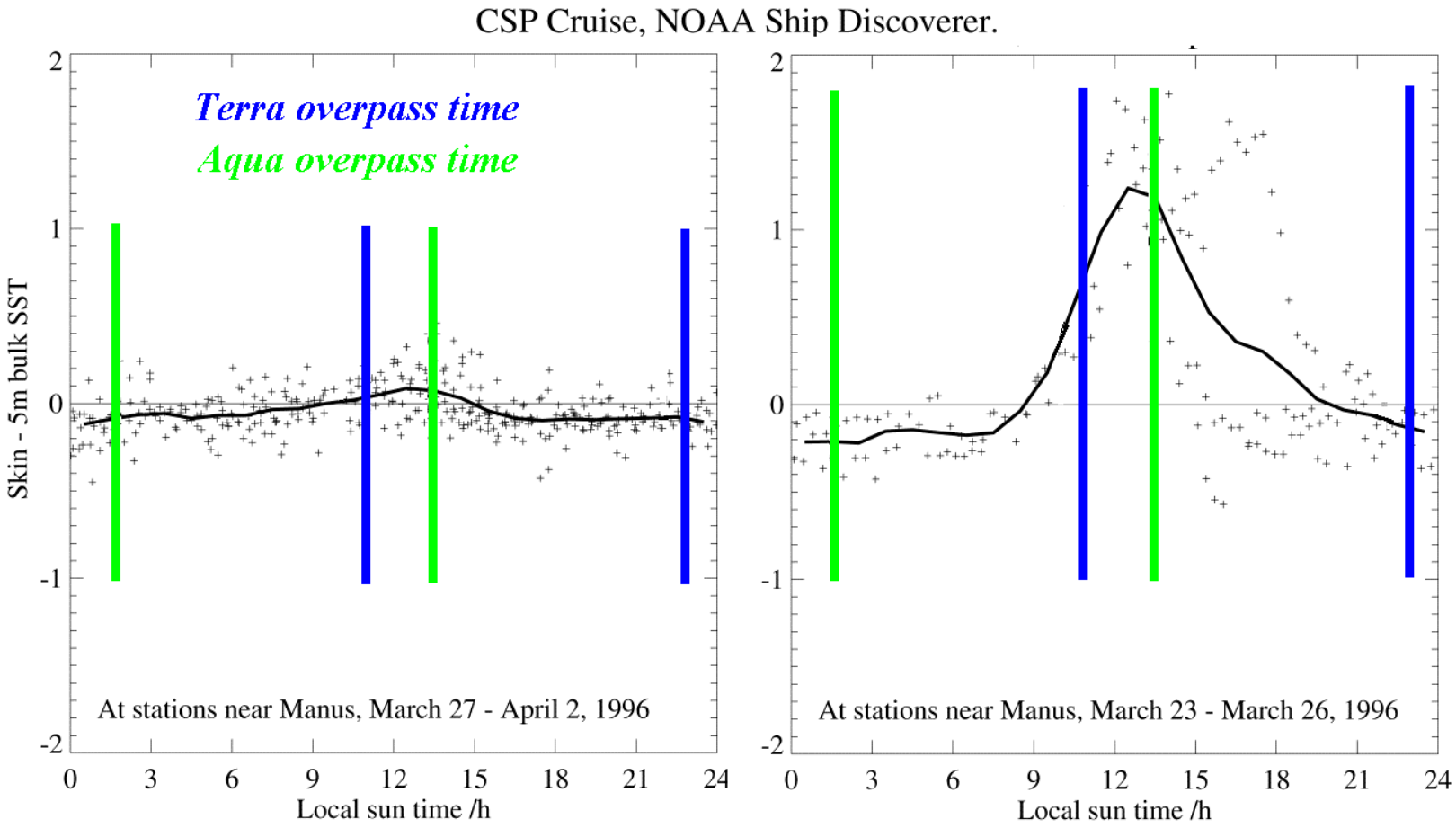


Wind speed dependence of diurnal & skin effects

NB – Reynolds' OI SST fields are 'calibrated' to bulk temperatures!



How skin and diurnal thermocline influence satellite measurements



Wind speed >~5ms^{-1}

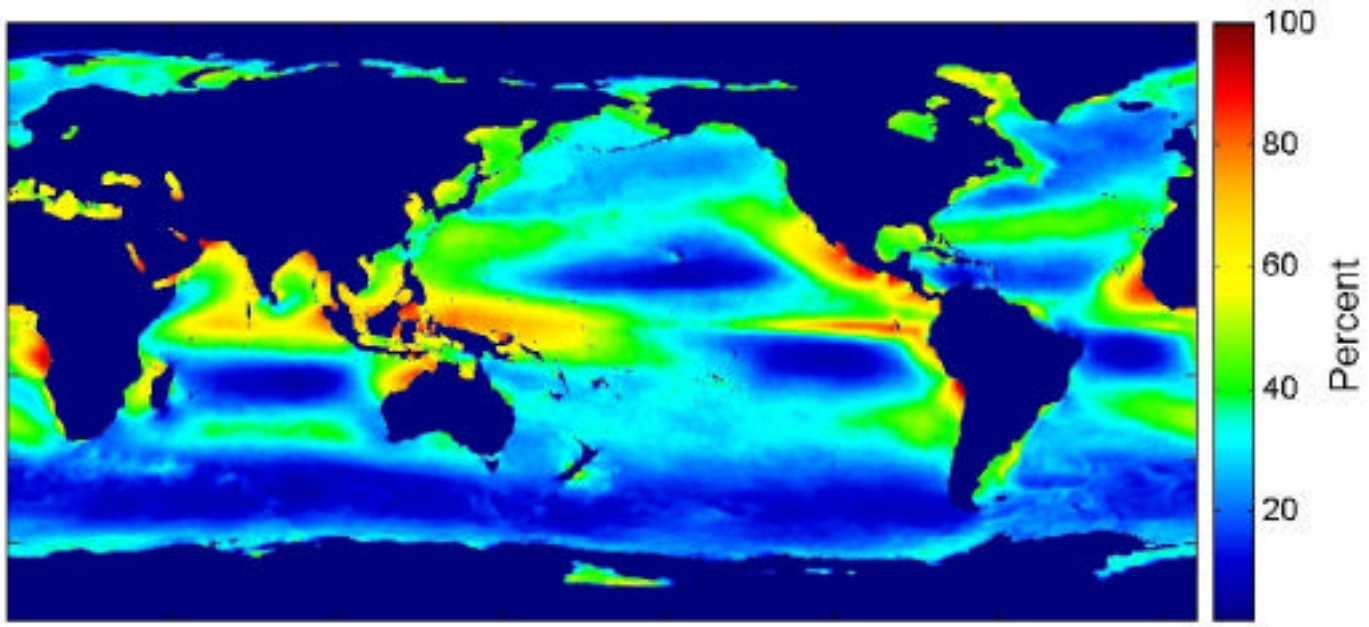
Wind speed <<5ms^{-1}

Wind speed criterion for SST validation

For winds > ~6m/s, relationship between skin and bulk SSTs becomes quite well behaved, at the level of ~0.1K. In these conditions bulk SST may be used to validate satellite-derived SSTs.

See Donlon, C. J., P. J. Minnett, C. Gentemann, T. J Nightingale, I. J. Barton, B. Ward and J Murray, 2001. Towards improved validation of satellite sea surface skin temperature measurements for climate research. ***J. Climate***. In the press.

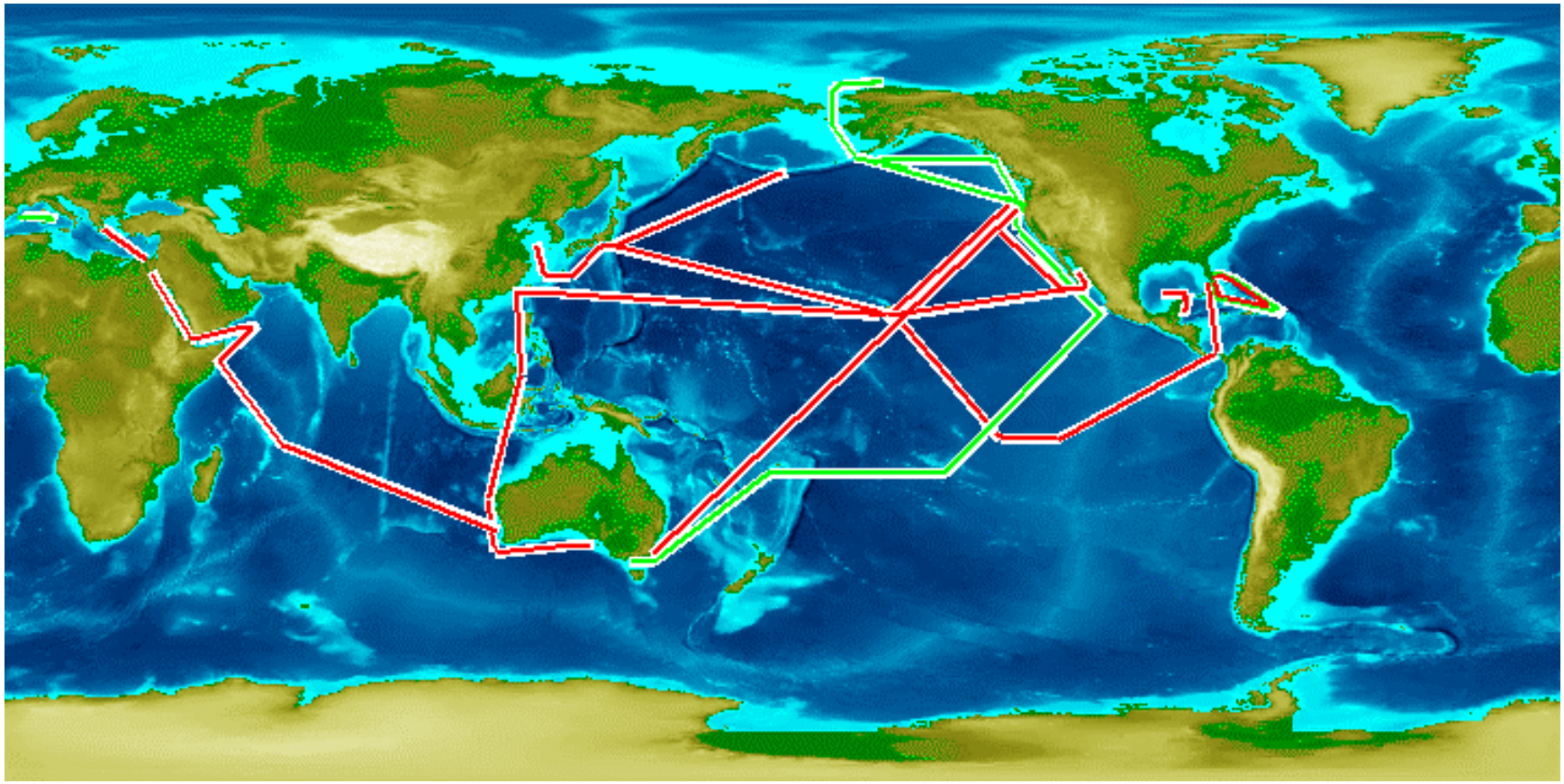
Distribution of wind speed <6ms^{-1}



Buoy data can be used, with caution, in blue areas

From Donlon, C. J., P. J. Minnett, C. Gentemann, T. J Nightingale, I. J. Barton, B. Ward and J Murray, 2001. Towards improved validation of satellite sea surface skin temperature measurements for climate research. ***J. Climate***. In the press.

M-AERI Cruises since launch of *Terra* MODIS

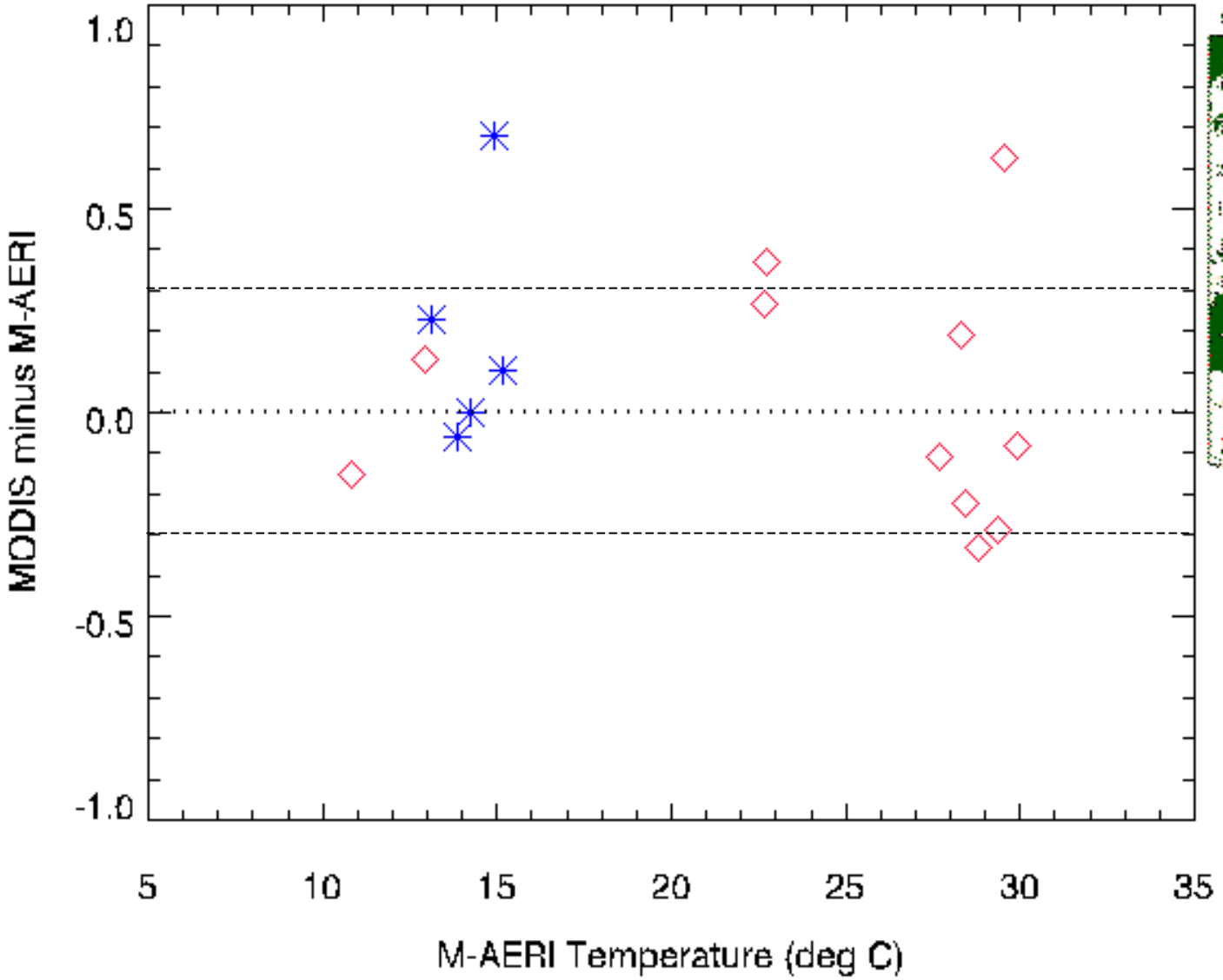


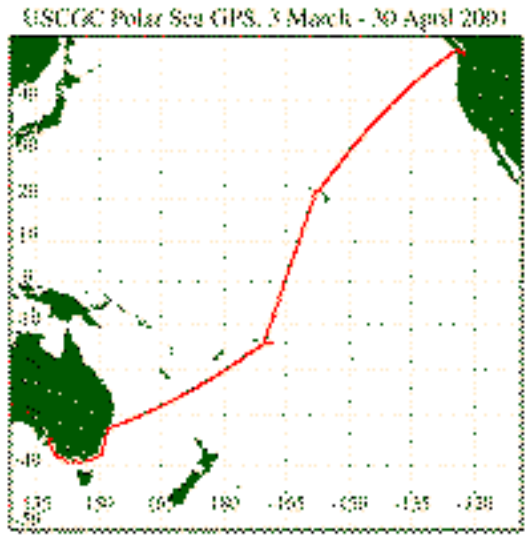
In 2000

In 2001

MODIS : M-AERI Matchups

Red=Pacific March-April 2001, Blue = Mediterranean - April,2000





$\overline{\Delta T}$ = 0.08K

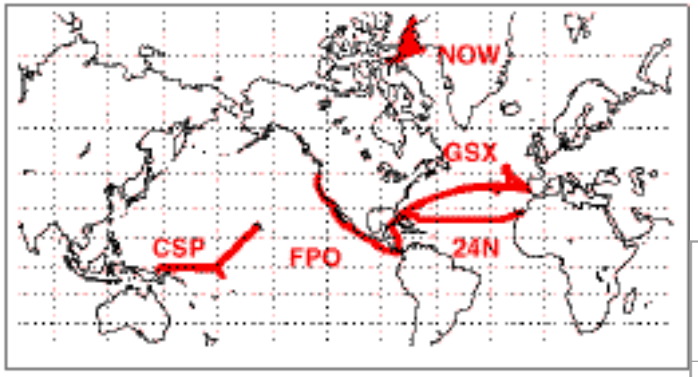
$\Delta T'$ = 0.3K

Remove two outliers :

$\overline{\Delta T}$ = 0.00K

$\Delta T'$ = 0.21K

AVHRR-MAERI SST validation experience



M-AERI validation of Pathfinder SSTs

Cruise Name	N	Mean K	St. Dev. K
CSP 1996	23	0.16	0.20
24N 1998	16	0.03	0.18
GASEX 1998	168	-0.01	0.25
FPO 1998	47	0.27	0.40
NOW 1998 (Arctic)	176	0.24	0.44
Total, all data	430	0.13	0.37
Total, excluding NOW data	254	0.06	0.29

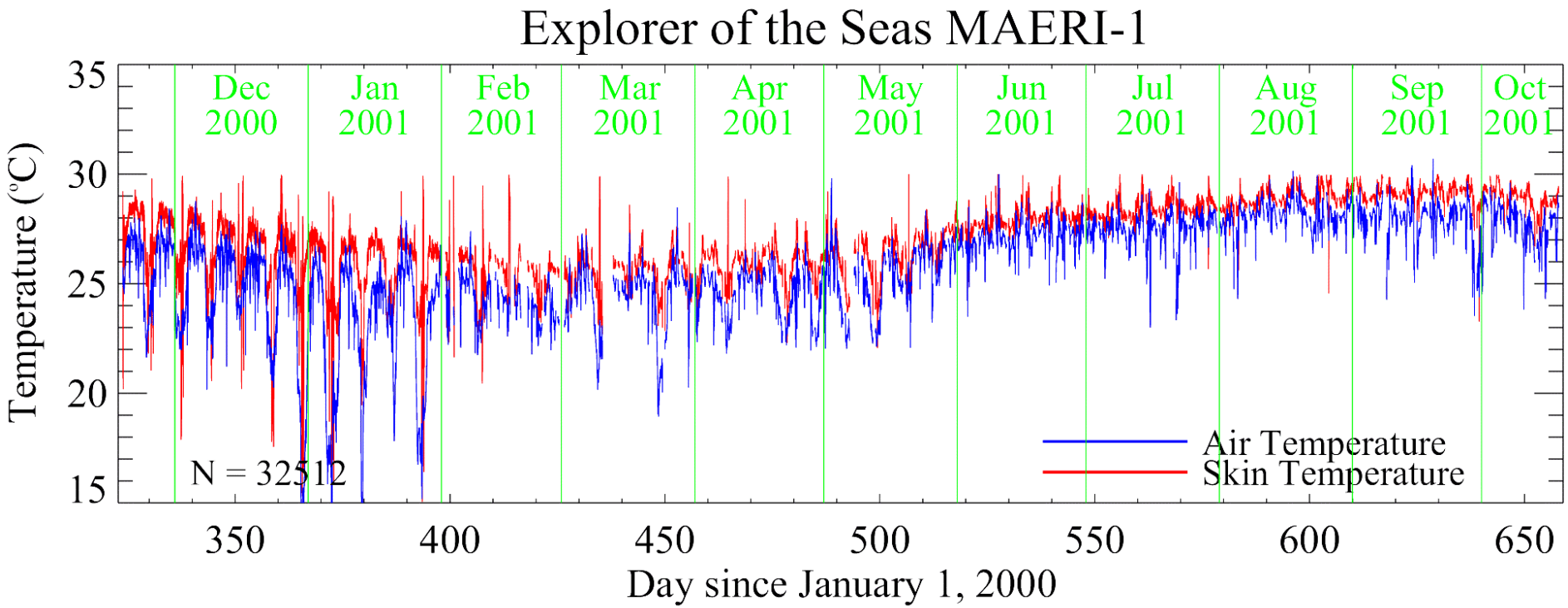
Using skin temperatures reduces the uncertainties by about a factor of two.

See Kearns *et al*, 2000, ***Bull. Am. Met. Soc.*, 81**, 1525-1536

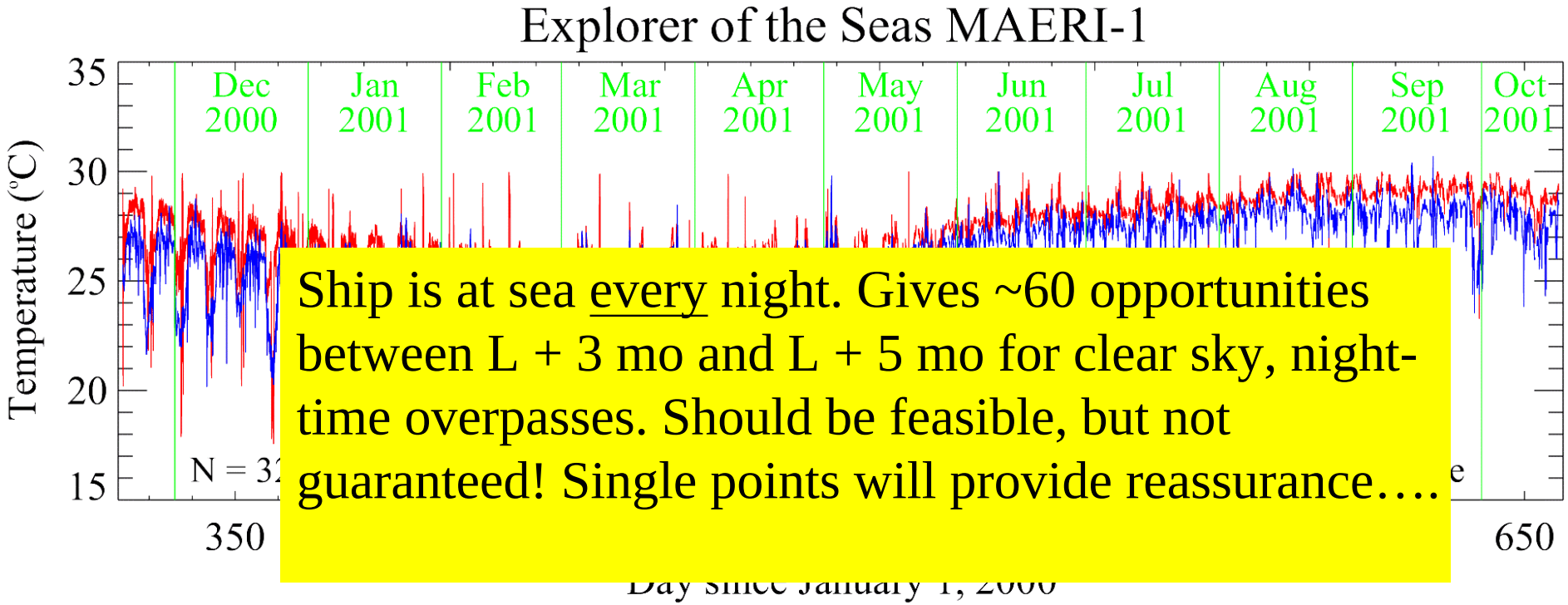
Time-series of M-AERI measurements on *Explorer of the Seas*

The *Explorer of the Seas* is a Royal Caribbean Cruise Liner, operating a weekly schedule out of Miami. It is outfitted as an oceanographic and atmospheric research vessel, very suitable for satellite validation. For more details see http://www.rsmas.miami.edu/rccl/.

M-AERI data from *Explorer of the Seas*

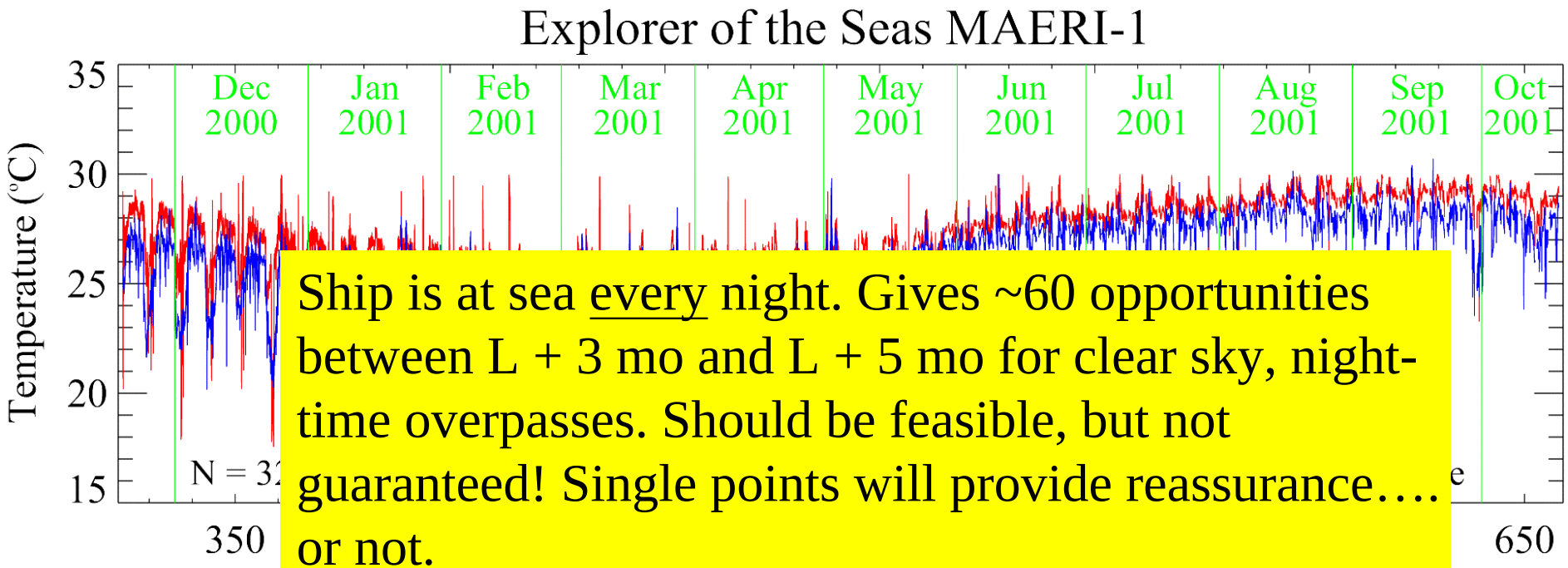


M-AERI data from *Explorer of the Seas*



Ship is at sea <u>every</u> night. Gives ~60 opportunities between L + 3 mo and L + 5 mo for clear sky, night-time overpasses. Should be feasible, but not guaranteed! Single points will provide reassurance….

M-AERI data from *Explorer of the Seas*



Ship is at sea <u>every</u> night. Gives ~60 opportunities between L + 3 mo and L + 5 mo for clear sky, night-time overpasses. Should be feasible, but not guaranteed! Single points will provide reassurance…. or not.

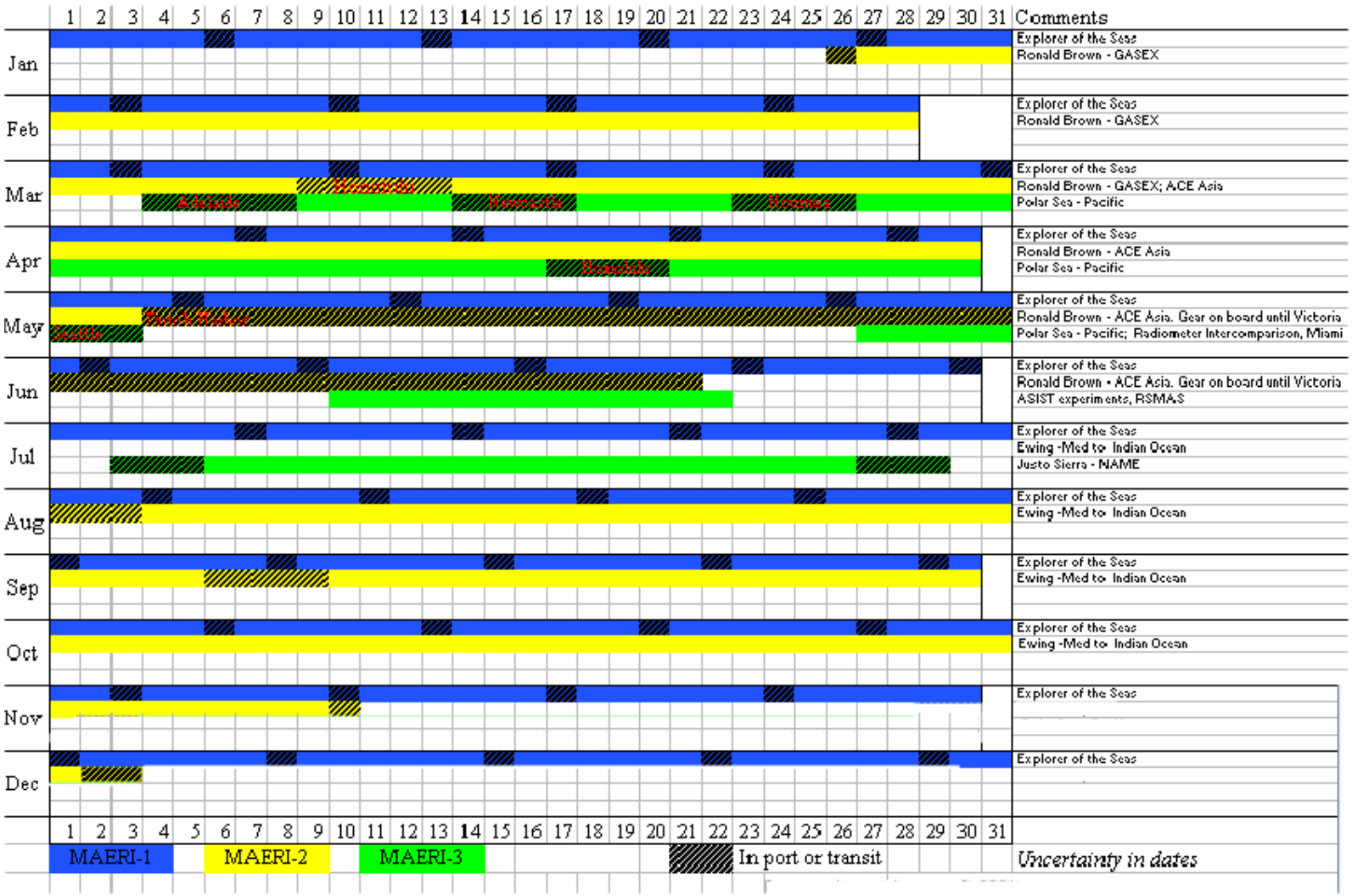
It will take time to fill in parameter space (scan-angle effects, aerosols……)

Cruise Schedule - 2001

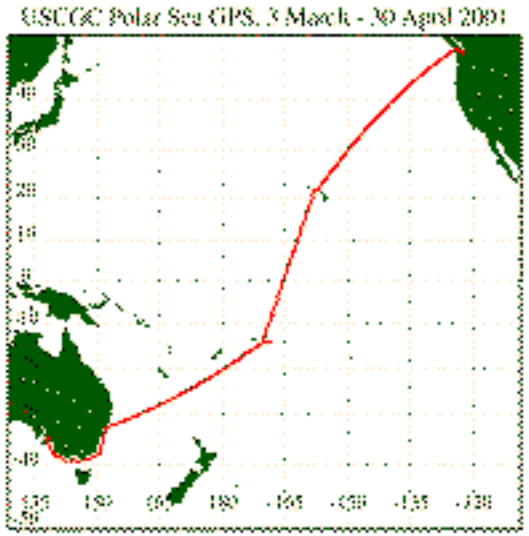
Project name	Ship	Departure Date	Departure Port	Arrival Date	Arrival Port	Comments
Royal Carribean	Explorer of theSeas	Every Saturday	Miami	Every Saturday	Miami	7 day cruises in Eastern Carribean. Saturday to Saturday.
GASEX 2001	NOAA S Ronald H. Brown	27 January 2001	Miami	8 March 2001	Honolulu	In equatorial Pacific. At Panama on 2 February.
Pacific Transect	USCGC Polar Sea	9 March 2001	Adelaide, Australia	1 May	Seattle	Adelaide -5 days; Newcastle 14-18 Mar; Noumea 23-27 Mar; Honolulu 17-21 Apr.
ACE-Asia	NOAA S Ronald H. Brown	14 March 2001	Honolulu	3 May 2001	Dutch Harbor	Returns to Seattle 16 June.
Radiometer Workshop	R/V F.G. Walton-Smith	30 May 2001	Miami	31 May 2001	Miami	2-days in local waters
North American Monsoon Expt.	R/VJusto Sierra	6 July 2001	Tuxpan, Mexico	26 July 2001	Tuxpan, Mexico	Western Carribean
Eastern Mediterranean, Red Sea, Gulf of Aden, Arabian Sea, and across Indian Ocean.	R/V Ewing	4 August 2001	Pireus, Greece	2 December 2001	Fremantle, Australia	Djitouti 19-21 August; Djibouti 12-13 Sept; Seychelles 24 Sept-06 Oct, Fremantle 23-27 Oct.

http://rsmas.miami.edu/ir/MAERI2001.html

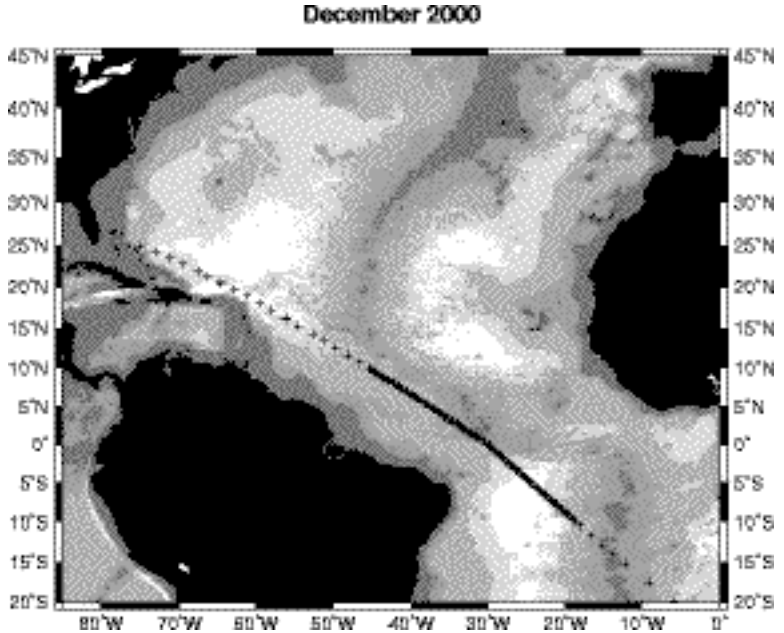
Cruise Schedule -2001



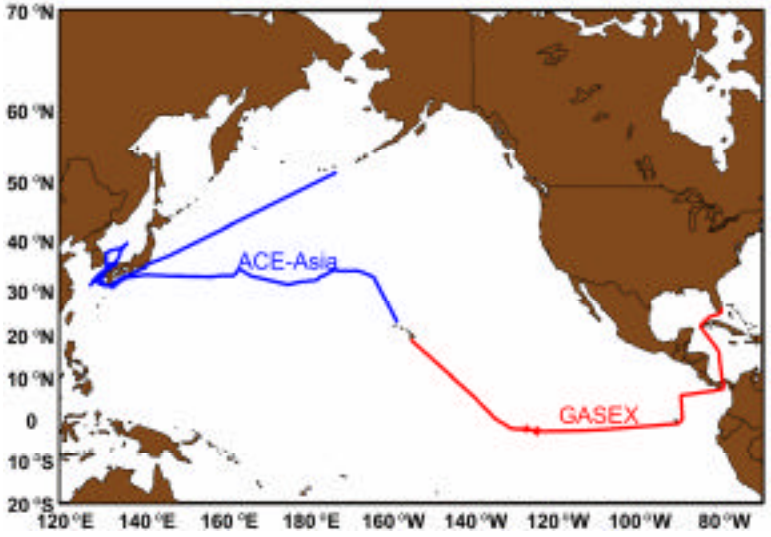
Trans-oceanic sections



USCG Ice-breakers across the Pacific, twice each year

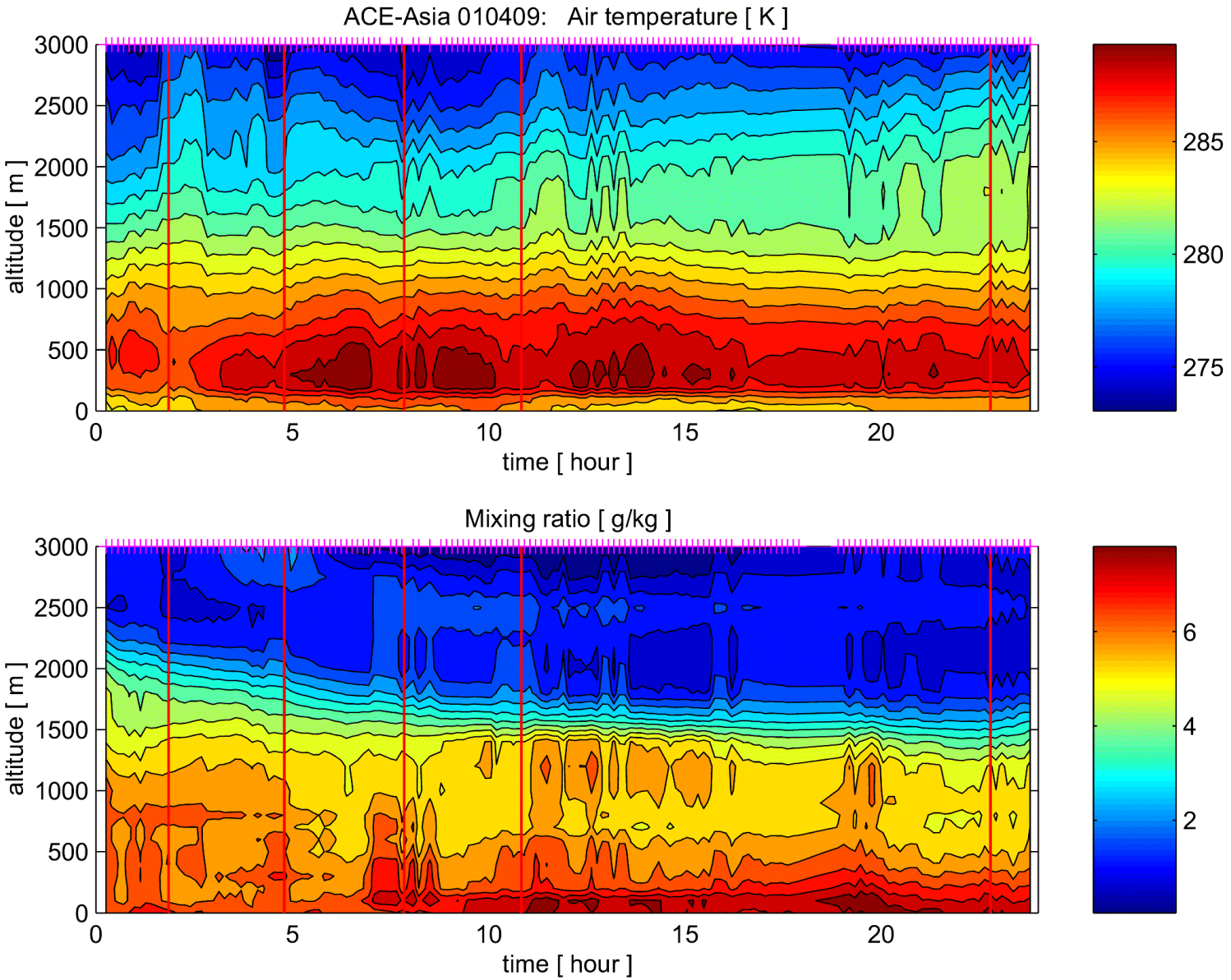


Research cruises, e.g. NOAA S *Ronald H. Brown*



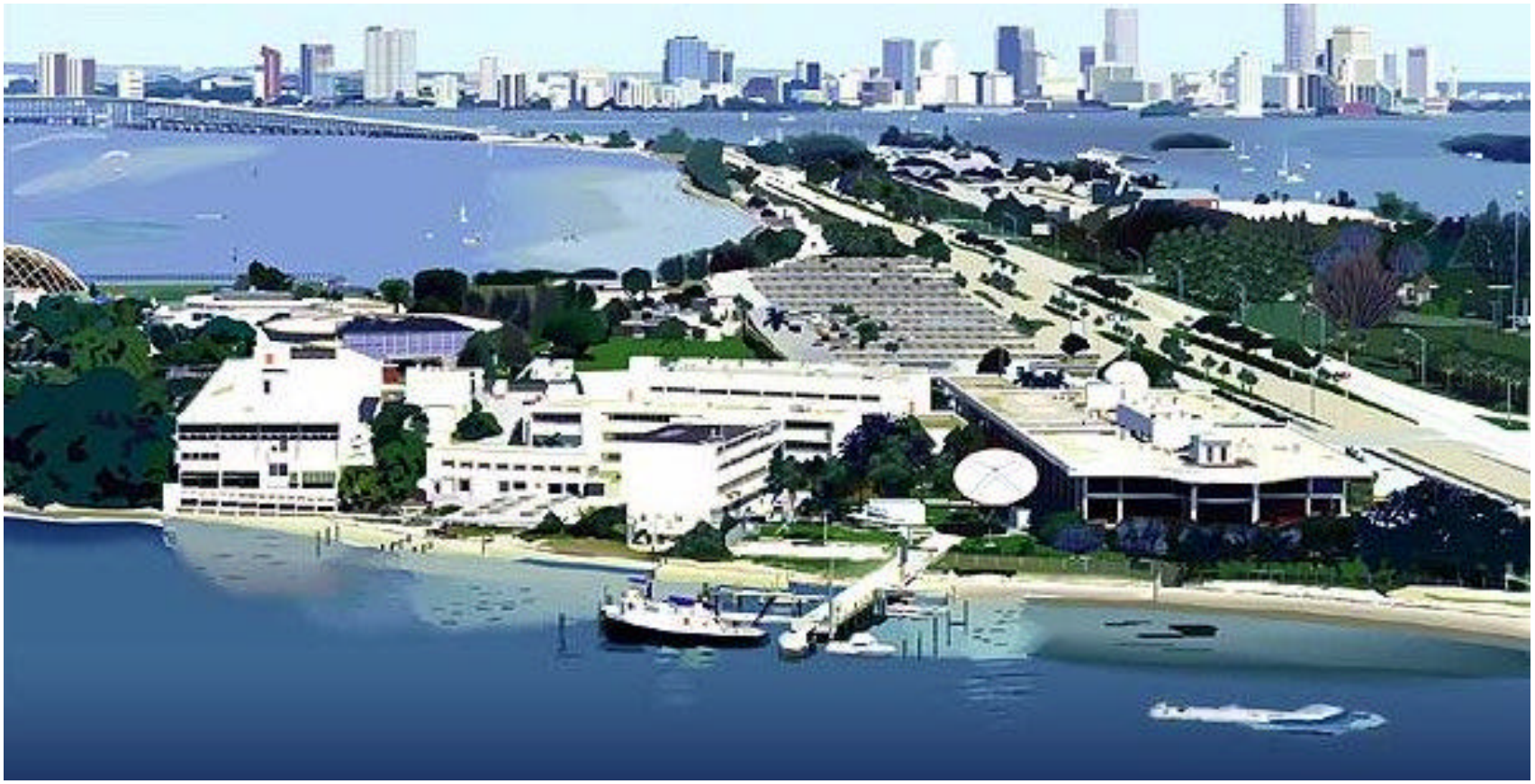
Container vessels, e.g. SAFMARINE - USA to SA along WOCE AX8 in Atlantic, several times each year

Atmospheric retrievals



Conclusions

- M-AERI and ancillary sensors provide a critical validation tool for *AIRS*
- Procedures tried and tested on many cruises
- SST validation (AVHRR and *Terra* MODIS) producing valuable results
- SST validation cruises provide measurements of other pertinent variables.



pminnett@rsmas.miami.edu


STOP